Network Enabled Operations Spiral II UAS Demonstration 5

Simulation Report

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16. Abstract

The Federal Aviation Administration (FAA) and a consortium of industry partners known as the Network Enabled Operations (NEO) Spiral II Team have partnered to investigate and demonstrate facets of near-term implementations of network-enabled information sharing and interagency communication and collaboration. The research focused on utilizing the current System Wide Information Management (SWIM) architecture being deployed by the FAA to demonstrate concepts supporting the integration of Unmanned Aircraft System (UAS) operations into the National Airspace System (NAS). This report documents the results of the NEO Spiral II UAS Demonstration 5 (Demo 5) limited-scope human-in-the-loop (HITL) study conducted on September 20-21, 2011.

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EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) and a consortium of industry partners known as the Network Enabled Operations (NEO) Spiral II Team have partnered to investigate and demonstrate facets of near-term implementations of network-enabled information sharing and interagency communication and collaboration. The research focused on utilizing the current System Wide Information Management (SWIM) architecture being deployed by the FAA to demonstrate concepts supporting the integration of Unmanned Aircraft System (UAS) operations into the National Airspace System (NAS).

This spiral of work culminated in two demonstrations using distributed networks of FAA systems of record involving "live" and simulated UAS flights in the NAS. This report documents the results of the NEO Spiral II UAS Demonstration 5 (Demo 5) limited-scope human-in-the-loop (HITL) study conducted on September 20-21, 2011. Demo 5, in part, served as a "dry run" for the subsequent NEO Spiral II UAS Demonstration 6 (Demo 6), an activity in which a UAS was flown live at the Warren Grove, New Jersey Air National Guard Gunnery Range. Demo 6 was conducted on September 28, 2011.[1]

The research objectives of the Demo 5 real-time HITL study are consistent with the overall objectives of the Spiral II program, which were to explore and demonstrate SWIM-enabled services and 4 dimensional trajectory based operations (4D TBO), and to inform the safety case for UAS integration into the NAS. Specific objectives of Demo 5 include the following:

- To explore and demonstrate improved coordination and collaboration among NAS users given the availability of enhanced flight data information to streamline communication and data flow within Air Traffic Control (ATC) services
- To explore and demonstrate improved predictability of UAS flight operations within ATC services given the availability of enhanced flight data information

The simulated UAS platform used for Demo 5 was the AAI Corporation RQ-7B Shadow 200. The HITL simulation scenarios specifically explored UAS operations during normal case and event driven conditions. The scripted events included a temporary loss of the UAS control and communication link, a dynamic reroute whereby the UAS crew requested a change to the UAS flight plan, and a strategic air traffic conflict that required ATC to initiate a corrective action. The scenarios were explored both with and without NEO services and (limited) 4D TBO enhancements. Both subjective and objective data were collected at all times throughout the exercise.

Due to the limited scope of the HITL simulation, a majority of the subsequent findings are based upon subjective data. The results of the study suggest that the inclusion of NEO services and limited 4D TBO technologies provide for improved coordination between ATC and the UAS crew in the scenarios as simulated. Study observations also appear to show that ATC experienced improved predictability of UAS operations during lost link events, as well as increased ease of coordination of flight plan amendments and reroutes with the UAS crew when these concepts were implemented. With further refinement of the procedures and technologies presented, the general concepts simulated appear to merit further exploration.

[1] For a description of the overall demonstration project, see "NEO Spiral II Final Report Executive Summary" document D794-10221-1, January 25, 2012.

1. Introduction

1.1 Purpose

The Federal Aviation Administration (FAA) and a consortium of industry partners known as the Network Enabled Operations (NEO) Spiral II Team have partnered to investigate and demonstrate facets of near-term implementations of network-enabled information sharing and interagency communication and collaboration. The research focused on utilizing the current System Wide Information Management (SWIM) architecture being deployed by the FAA to demonstrate concepts supporting the integration of Unmanned Aircraft System (UAS) operations into the National Airspace System (NAS).

This spiral of work culminated in two demonstrations using distributed networks of FAA systems of record involving "live" and simulated UAS flights in the NAS. This report documents the results of the NEO Spiral II UAS Demonstration 5 (Demo 5) limited-scope human-in-the-loop (HITL) study conducted on September 20-21, 2011. Demo 5, in part, served as a "dry run" for the subsequent NEO Spiral II UAS Demonstration 6 (Demo 6), an activity in which a UAS was flown live at the Warren Grove, New Jersey Air National Guard Gunnery Range. Demo 6 was conducted on September 28, 2011.[2]

1.2 Objectives

The research objectives of the Demo 5 real-time HITL study are consistent with the overall objectives of the Spiral II program, which were to explore and demonstrate SWIM-enabled services and 4 dimensional trajectory based operations (4D TBO), and to inform the safety case for UAS integration into the NAS.

A major challenge in progressing UAS operations in the NAS is to understand the performance characteristics of each system as the two interact. As such, the specific research objectives for Demo 5 were:

- To explore and demonstrate improved coordination and collaboration among NAS users given the availability of enhanced flight data information to streamline communication and data flow within Air Traffic Control (ATC) services
- To explore and demonstrate improved predictability of UAS flight operations within ATC services given the availability of enhanced flight data information

1.3 Scope

The Demo 5 simulation was part of a series of simulation, engineering, and demonstration activities under the NEO Spiral II Program. Demo 5 was a limited-scope HITL study designed to explore the impact of network-enabled information sharing on both routine and contingency UAS operations in the NAS. This study facilitated a proof-of-concept architecture to explore the feasibility of the proposed operations.

[2] For a description of the overall demonstration project, see "NEO Spiral II Final Report Executive Summary" document D794-10221-1, January 25, 2012.

The simulated UAS platform used for Demo 5 was the AAI Corporation RQ-7B Shadow 200 (Shadow). The Shadow and industry-provided NEO services were integrated into an enhanced ATC simulation environment at the FAA William J. Hughes Technical Center (WJHTC). The FAA's Research and Development (R&D) External Enclave served as the network and communications gateway between the distributed systems to complete the simulation environment. The intent of the study was to serve as a "dry run" for Demo 6 and to provide early insight into the value of the concepts, infrastructure, and operational procedures that were the focus of NEO Spiral II.

The Demo 5 simulation was strictly exploratory in nature and does not validate or approve the proposed procedures or technologies under study. In addition, the Shadow UAS was chosen to represent the UAS characteristics of interest; this study is not an evaluation of the specific UAS platform.

2. Method

HITL simulation is a powerful research technique that can be used to explore future operational concepts without posing risk to the operators and systems under study. This type of research permits human participants to interact in a high fidelity, real-time, realistic, and immersive setting, while allowing the researcher to gain insight and collect valuable data regarding their actions and the potential impact on the proposed environment. Information assimilated from Subject Matter Experts (SME), cognitive walk-throughs, and analytical studies were used to develop the approach method for Demo 5. Key components are described in this section.

2.1 Assumptions and Limitations

Since UAS are restricted as to where and how they operate in the NAS today, some basic rules and procedures for an integrated environment outside Special Use Airspace (SUA) had to be defined for the purposes of the simulation. The applicable assumptions and operating procedures follow.

- UAS operations were fully integrated in the simulated NAS environment (i.e., UAS operations were not under the conditions of a Certificate of Waiver or Authorization)
- The simulated airspace and sectors were adapted and augmented beyond the capabilities of current real world systems and implementations (i.e., adaptation was developed/modified to support the concepts being studied)
- All flights were conducted under Instrument Flight Rules (including no Visual Flight Rules aircraft within the scenario)
- No visual separation
- Current separation standards applied
- Collision Avoidance and Sense and Avoid issues were outside the scope of the study
- Scenario operations remained at or below FL100
- No restricted areas or SUA were active in the simulated environment
- The Shadow ground control station (GCS) was located within 1 nm of departure and/or arrival points
- Aircraft Intent Description Language was of limited scope and capability within this demonstration and therefore facilitated a limited exchange of 4D TBO information
- The period of data to be analyzed began and ended at traffic pattern altitude approximately 1000 feet mean sea level (MSL)

- The UAS sensor operator position was not staffed

Additionally, some differences exist between a UAS GCS used in the field today and the GCS used in this simulation. Differences recognized by the research team included:

- A different communication interface
- The coupling and utilization of a simulated Flight Management System (sFMS) to the UAS GCS
- The availability of NEO services in select scenarios

The results discussed in this study are based on the minimum possible number of participants, and a limited number of observations. Thus, there was no statistical power for inference, and results cannot be generalized to the population of interest, nor considered conclusive.

2.2 Participants

The human subjects observed in this study consisted of one Air Traffic Controller, one UAS Pilot, and one flight management system (FMS) Operator.

Study participants signed an informed consent statement prior to participation. Participants were subjected to minimal risk, meaning that the probabilities of harm or discomfort anticipated in this simulation were not greater than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests. Strict adherence to all federal, union, and ethical guidelines was maintained throughout the study.

Study objectives did not include assessment of individual controller or pilot performance or competency. The focus was on the collection of operational and subjective data that will assist in the evaluation of the concepts being explored.

2.2.1 Air Traffic Controller

One ATC SME participated in the role of Air Traffic Controller for this study. The participant was provided by the FAA and possessed experience and familiarity with the Standard Terminal Automation Replacement System (STARS), as well as real-world air traffic management (ATM) experience. The Air Traffic Controller participant was trained to sufficiency on the NEO systems, services, and technologies which were new to the operational environment.

2.2.2 UAS Pilot

One UAS Pilot provided by AAI Corporation (a NEO consortium partner) participated in the study. The participant was qualified and current as a pilot in command for the Shadow platform.

2.2.3 Flight Management System Operator

One participant served as the operator of the sFMS, interacting with the Shadow Pilot as a member of the flight crew. The FMS Operator was provided by a NEO consortium partner, GE Aviation Systems

LLC. This flight crew role was only staffed during runs involving NEO services and the sFMS equipment.

2.3 Research Partners

2.3.1 Industry Partners

The FAA partnered with the NEO Spiral II Team on this research endeavor. In addition, the FAA leveraged its Cooperative Research and Development Agreements (CRDA)[3] with two industry partners, who provided assets to support the conduct of this study. Under a formalized CRDA with the FAA, AAI Corporation provided the RQ-7B Shadow 200 simulator software platform, and assisted with its installation into the FAA's Next Generation Air Transportation System (NextGen) Integration and Evaluation Capability (NIEC) at the WJHTC. Under a separate CRDA with the FAA, GE Aviation Systems provided use of proprietary software that couples the sFMS to the Shadow simulator.

2.3.2 FAA

2.3.2.1 Research Sponsor

The FAA's Technology Development and Prototyping Division (ANG-C5) was the sponsoring organization responsible for the planning and funding of this project, providing the overall leadership and direction. This office also served as liaison to the industry partners.

2.3.2.2 Research Team

With cooperation of the industry partners, the FAA's Engineering and Development Services Division (ANG-C3) designed and conducted the real-time HITL simulation. A Principal Investigator was responsible for the overall administration of the exercise and directed the research team staff. Responsibilities of the team included development and preparation of all experimental materials, design of the study, simulator preparation and operation, study execution, data collection, and data analysis. The research team also supplied the simulation support staff including Simulation Pilots, Ghost Controllers, laboratory experts, and SME Observers.

2.3.2.3 Simulation Pilots

Four Simulation Pilots were required for the study. The Simulation Pilots controlled the manned aircraft traffic in the scenarios, emulated their pilot communications and actions, and responded to ATC instructions. Though a key element of each scenario environment, their actions were not the subject of study or evaluation.

[3] The CRDA between AAI Corporation and FAA WJHTC (09-CRDA-0259) is valid beginning 6/26/09. The CRDA between GE Aviation Systems, LLC and FAA WJHTC (09-CRDA-0259) is valid beginning 6/19/09.

2.3.2.4 Ghost Controllers

One ATC SME served as the ‘Ghost Controller’ who controlled traffic in sectors adjacent to the test sector of interest. The Ghost Controller transferred control of aircraft, implemented traffic flow relief, and responded to test participant instructions for specific aircraft outside of the test sector. The Ghost Coordinator had the ability to communicate on all simulated frequencies. In preparation for the simulation, the Ghost Controller gained familiarity with the airspace, scenarios, and procedures during scenario development and shakedown. Though a key element of each scenario environment, the Ghost Controller’s actions were not the subject of study or evaluation.

2.3.2.5 Laboratory Services

The laboratory support team was responsible for preparing and running all required laboratory hardware for use in the simulation (e.g., UAS and ATC simulators, communications equipment, audio/visual recorders). They were also responsible for developing the software components of the exercise (e.g., aircraft models, airspace environment, traffic scenarios) and capturing and storing all simulation data.

2.3.2.6 Subject Matter Expert Observers

Two SME were required to serve as SME Observers for this simulation. One SME observed the Shadow Pilot in the UAS area and the other observed the Air Traffic Controller in the ATC area. The SME Observers monitored the frequencies of the positions they observed and manually collected supplemental simulation data.

2.4 Laboratories and Equipment

Demo 5 utilized a distributed simulation environment involving the NEO infrastructure, the FAA’s R&D External Enclave, and simulation and operational assets located at the WJHTC.

Figure 1 highlights the components of the distributed simulation environment used for Demo 5. Key laboratories and equipment included:

- NEO/Data Exchange (DEX) equipment and services
- NIEC
- UAS simulator
- FMS simulator
- ATC workstations
- Voice communication system
- Target Generation Facility (TGF)
- Simulation Pilot workstations
- R&D External Enclave network
- Workload Assessment Keypad

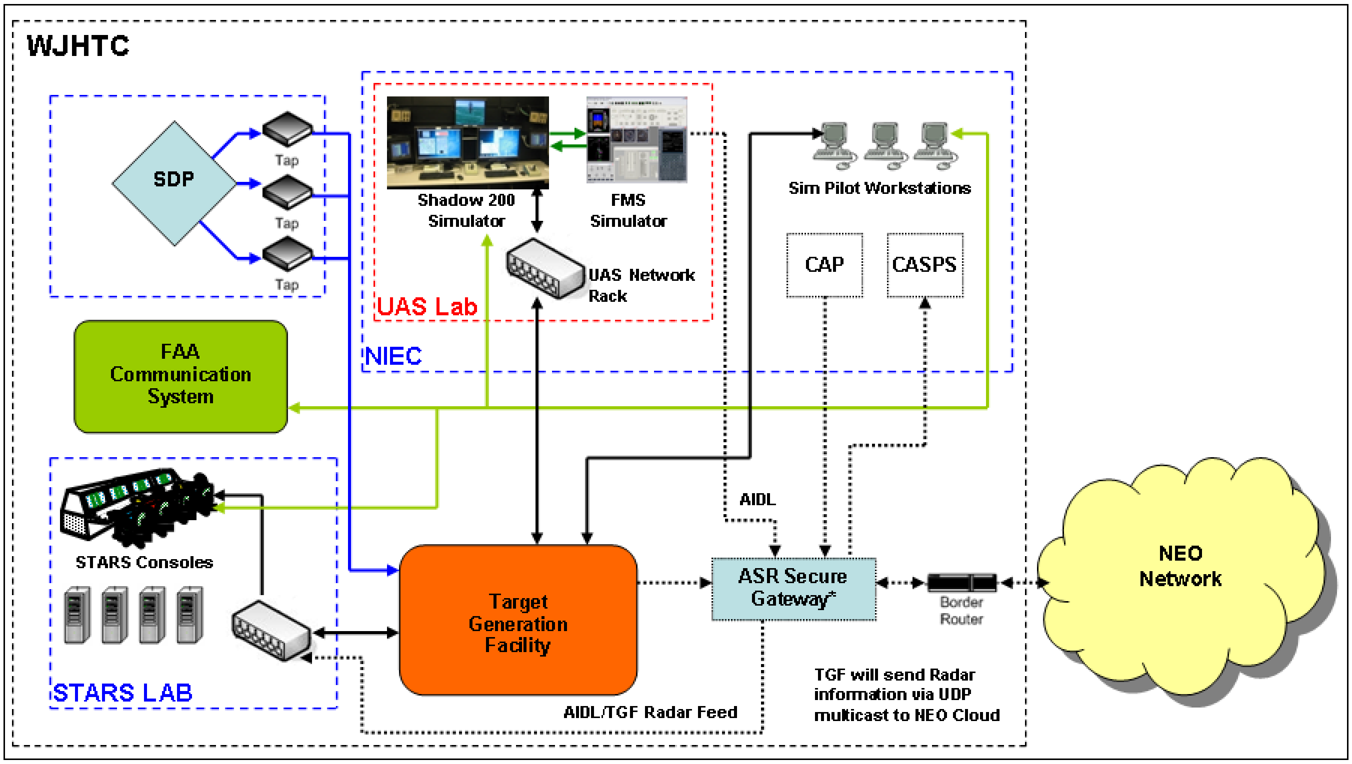

Figure 1: Distributed Simulation Environment

The NEO/DEX equipment and services provided SWIM-enabled information sharing services between the UAS (and sFMS) and ATC as described in the Network Enabled Operations Spiral II Final Report. For complete technical details on the NEO Spiral II architecture, capabilities, and development process, see section 3.1 of that report. The other key laboratory and equipment components are described in the sections that follow.

2.4.1 FAA Research and Development External Enclave

The FAA's R&D External Enclave served as the network and communications gateway between the distributed systems to complete the simulation environment. The simulation architecture involved multiple resources and systems partitioned throughout various facilities, thus requiring real-time connectivity and coordination among all of these assets. To facilitate this distributed simulation, both the NEO Spiral II Team and the FAA provided network infrastructure to accommodate the dissemination and exchange of data.

The NEO multi-protocol label switching (MPLS) network was a conglomeration of multiple systems allocated among the various industry partners of the NEO Spiral II Team, as seen in Figure 2.

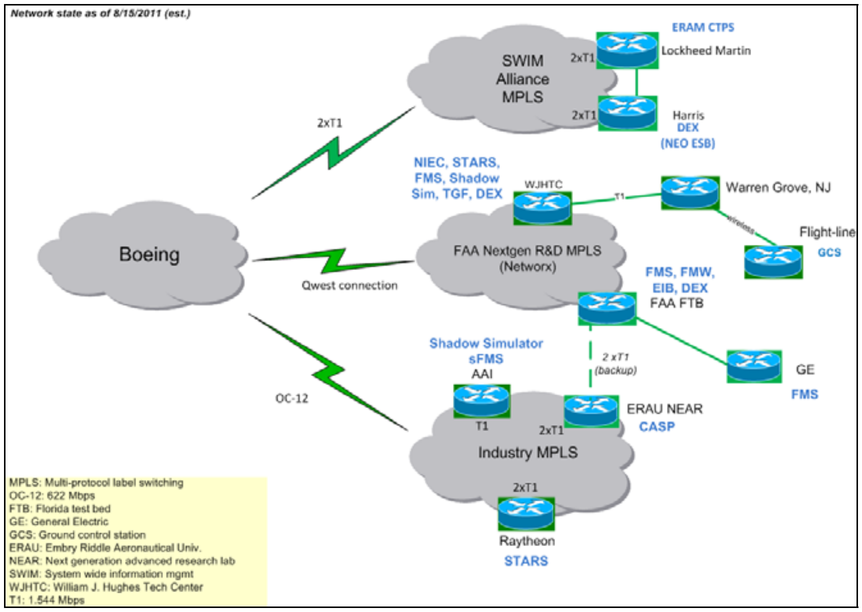

Figure 2. NEO Network Final State

Concurrently, the internal architecture at the WJHTC leveraged the FAA NextGen R&D Enclave (an MPLS network), which allowed the NEO MPLS network and users access to systems and resources located at the WJHTC. The overall FAA R&D network is depicted in Figure 3.

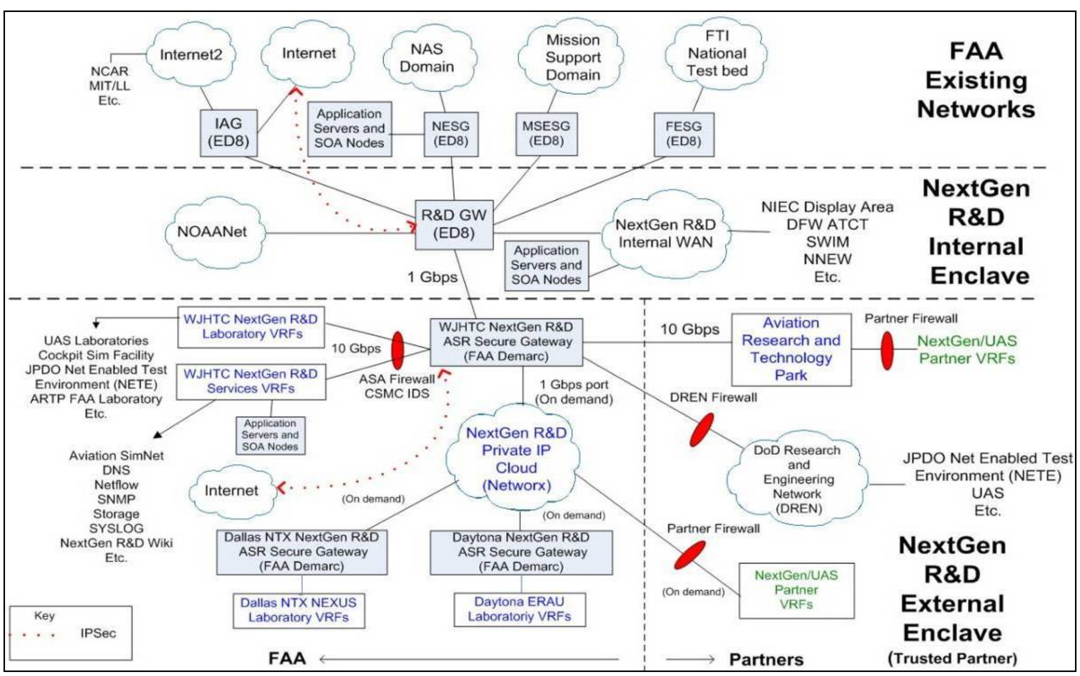

Figure 3. FAA NextGen R&D Network

2.4.2 NextGen Integration and Evaluation Capability

The NIEC allows for a flexible and rapid prototyping and simulation environment that can link and enable simulation-specific components as needed.

Figure 4 shows the floor plan layout of the NIEC. The UAS GCS, sFMS, and other supporting workstations in the UAS area were integrated into the Demo 5 distributed simulation.

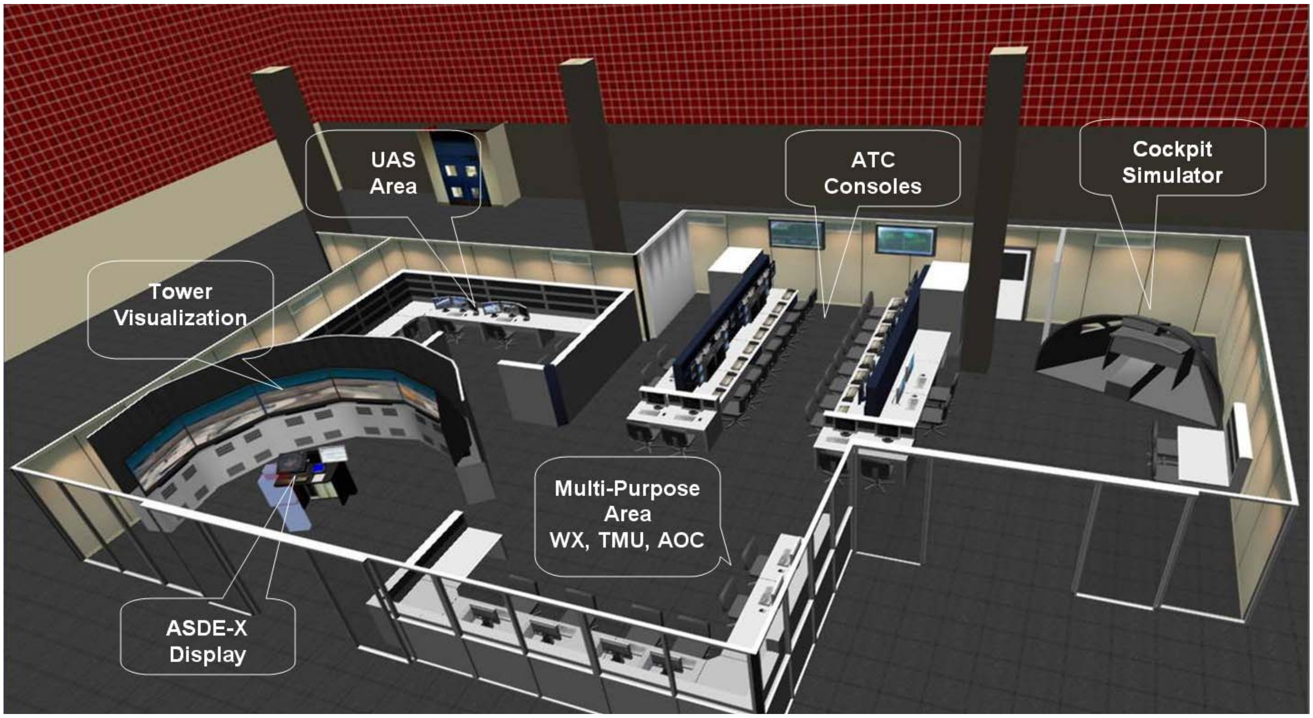

Figure 4: NIEC Floor Plan

2.4.2.1 UAS Simulator

The GCS is part of the Shadow hardware-in-the-loop simulator (HILSIM) located at the WJHTC. This simulator uses an RQ-7B Shadow 6 Degrees of Freedom (6 DoF[4]) model. The pilot interface of the HILSIM runs on a Linux workstation, with software written by CDL Systems (an AAI Corporation-contracted company). The HILSIM GCS is comprised of two stations, one used by the UAS Pilot and one used by another crewmember operating the payload; each has one monitor, one joystick, one QWERTY keyboard, and one mouse. The HILSIM also includes three workstations that simulate the aircraft and its aerodynamic performance profile. This software was written by AAI Corporation.

[4] 6 Degrees of Freedom (6 DoF) refers to motion of a rigid body in three-dimensional space, namely the ability to move forward/backward, up/down, left/right (translation in three perpendicular axes) combined with rotation about three perpendicular axes (roll, yaw, pitch). As the movement along each of the three axes is independent of each other and independent of the rotation about any of these axes, the motion indeed has 6 DoF.

The HILSIM development is a cooperative effort between AAI Corporation and the US Army. Dynetics, Inc., of Huntsville, Alabama, was contracted by the US Army to develop a high fidelity 6 DoF simulation of the block 1B airframe. The block 1B simulator has been tailored to interface with the Shadow FMS/Flight Control System (FCS) avionics (the new avionics package of the RQ-7B Shadow system). Dynetics has since been responsible for the development and configuration control of the 6 DoF aero model and supports software on the simulation PC (developed by the DoD Joint Modeling and Simulation System). AAI Corporation has been similarly responsible for the avionics portion of the simulation code. The AAI Corporation portion of the HILSIM code has been developed and controlled using ISO 9000 standards and other approved software development procedures, including quality assurance reviews and peer level software reviews.

For this simulation, the Shadow simulator was utilized and operated by a UAS Pilot who followed pre-defined flight scenarios.

Figure 5 displays the Shadow GCS at the WJHTC.

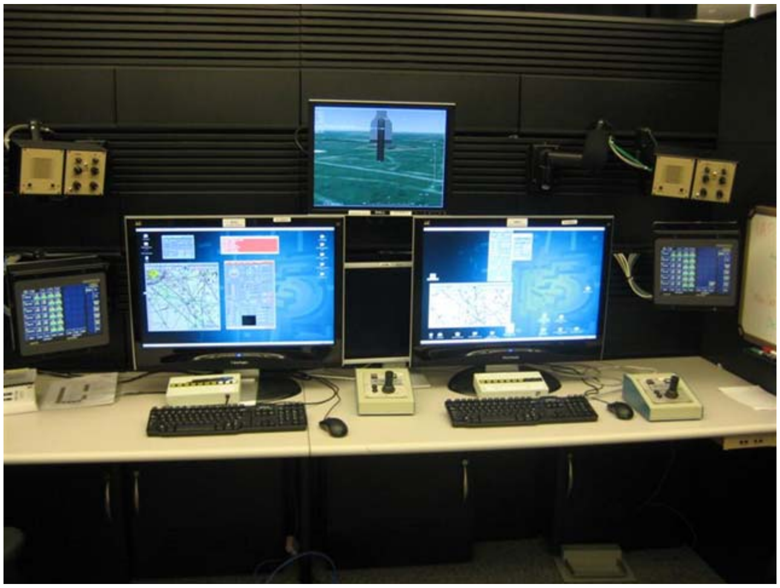

Figure 5. Shadow Ground Control Station

2.4.2.2 <u>Flight Management System Simulator</u>

The sFMS was designed as a full-function desktop flight management system that makes use of actual FMS hardware and software. Combined with high fidelity display emulations, the sFMS offers a unique simulation capability in a desktop configuration that can be integrated with other simulation systems in a distributed environment.

The basic system is a robust FMS environment that uses the actual FMS operational software combined with real navigation databases. The sFMS executes the actual Operational Flight Program code in its native environment. In addition, a PC workstation provides the real world interaction required by the FMS Operator, through an easy to use graphical user interface (shown in Figure 6). The PC workstation is comprised of two sections: the Labsim executable (the user interface) and the Real Time Process executable that includes the aircraft performance, flight control, and avionics models.

In addition, NEO services and limited 4D TBO capabilities/enhancements were added, which include both the Common Alerting Protocol (CAP) and trajectory predictor services. See the NEO Spiral II Final Report Executive Summary, Section 3.1.2.

Figure 6. sFMS Workstation Display

2.4.3 Air Traffic Control Workstations

Demo 5 utilized a STARS laboratory at the WJHTC to serve as the emulated ATM facility for the study. Specifically, STARS String 7 was isolated (from the NAS support operations network) to the R&D External Enclave and integrated into the distributed simulation. Two STARS workstations were configured for this study; one for the test sector of interest, the other for the combined position of the ghost sectors. In addition, the aforementioned NEO/4D TBO services/capabilities (such as the CAP service) were included within this environment. See NEO Spiral II Final Report Executive Summary, Section 3.1.2.

Each of the STARS workstations included a monitor, a keyboard, and a trackball and was configured to accommodate the appropriate approach control position. The workstations also had voice communications equipment to provide the capability to monitor/transmit on the simulated frequencies.

2.4.4 Voice Communication System

All positions (i.e., Controllers, UAS Pilot, FMS Operator, and Simulation Pilots) were equipped with voice communication systems that included frequency selection panels, headsets, microphones, and push-to-talk switches. This allowed for two-way communication between all positions in the simulated environment. All frequency communications were recorded for data collection and analysis.

2.4.5 Target Generation Facility

Demo 5 used the TGF to present air traffic scenarios. TGF is a software application developed by the FAA WJHTC to simulate air traffic that can be disseminated to both emulated and operational NAS systems.

TGF is a dynamic, real-time, air traffic simulation capability designed to generate realistic aircraft trajectories and associated digital radar messages for aircraft in a simulated airspace environment. Primarily, TGF is used to generate real time, interactive traffic in support of HITL simulations. Realistic traffic flows and voice communications are created in real time by Simulation Pilots operating the simulated TGF aircraft in response to ATC instructions.

TGF uses preset flight plans to generate radar track and data block information on the controller and simulation pilot displays. The TGF also provides an interface that allows the Simulation Pilots to enter flight plan changes. The TGF algorithms can control aircraft maneuvers so that they appear to the controllers to represent realistic aircraft climb, descent, and turn rates.

TGF also includes data reduction and analysis tools that allow researchers to capture and/or derive information about aircraft trajectories, aircraft proximity, performance characteristics and profiles, and other relevant data for use in subsequent analysis.

For this study, TGF was used in conjunction with STARS to present the traffic on the controller workstations. The TGF configuration used for this study was developed in accordance with the objectives established within this report.

2.4.6 Simulation Pilot Workstations

For this study, four simulation pilot workstations were used. Each workstation consisted of a computer, keyboard, monitor, and communication equipment. Simulation Pilots controlled TGF-generated aircraft by issuing commands on their respective workstations. These commands were pre-defined strings of alphanumeric characters that were entered using a standard workstation keyboard.

Each Simulation Pilot also had a two-dimensional, plan view display of traffic and a list of assigned aircraft to control. For each assigned aircraft, the simulation pilots possessed information regarding the aircraft’s current state and corresponding flight plan data.

2.4.7 Workload Assessment Keypads

A Workload Assessment Keypad (WAK) was present at the Air Traffic Controller and UAS Pilot positions. The WAK consisted of a push button panel with seven numbered buttons, as illustrated in

Figure 7. Using auditory and visual signals, the WAK prompted the participants to press a button to provide their instantaneous, subjective workload ratings.

In this simulation, the WAK were set to prompt the participants for a rating every four minutes. During the prompt, the numbered buttons on each device illuminated and emitted a brief tone. The participants indicated their current level of workload by pressing one of the numbered buttons, with “1” indicating low workload, “4” indicating typical workload, and “7” indicating high workload. The buttons remained illuminated for 20 seconds (or until a participant made a response). WAK data was collected and time stamped for each scenario run by a component of the FAA’s simulation system called the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE).

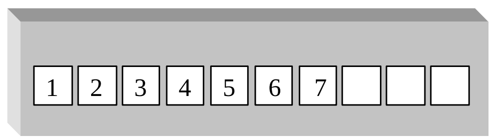

Figure 7. Workload Assessment Keypad

2.5 Materials

2.5.1 ATC Operational Procedures

ATC procedures were followed as they exist in present day (i.e., in conformance with FAA Order JO7110.65T). Additionally, 4D TBO concepts were demonstrated as outlined within the Demo Plan Procedures document.[5]

2.5.2 UAS Flight Operations

UAS flight operations were fully integrated with manned aircraft in the simulated NAS environment (i.e., UAS operations were not restricted to the conditions of a Certificate of Waiver or Authorization).

For runs not involving NEO services (and therefore no sFMS), the filed flight plan was pre-programmed and loaded directly into the GCS. The UAS Pilot was the sole operator of the UAS.

During runs involving NEO services (which included a sFMS coupled to the GCS), the filed flight plan was pre-programmed and loaded into the sFMS via a CAP message and an FMS Operator was added to the flight crew. The sole responsibility of the FMS Operator was to assist the UAS Pilot by operating the sFMS, which was supported by NEO services. The FMS Operator had the ability to monitor the Shadow’s voice communication frequency, but did not directly communicate with ATC by voice. Only the UAS Pilot communicated over the voice frequency with ATC.

[5] Boeing Research and Technology (2011). Network Enabled Operations Demonstration Plan/Procedures. Chantilly, VA.

2.5.3 Airspace

The Warren Grove SUA 5002A/B was used as the basis for the airspace design in this study. The SUA detailed boundaries are provided in Appendix A. For the purposes of this simulation, the SUA was treated as inactive. Figure 8 provides a graphical depiction of the Warren Grove SUA, which is located in central New Jersey.

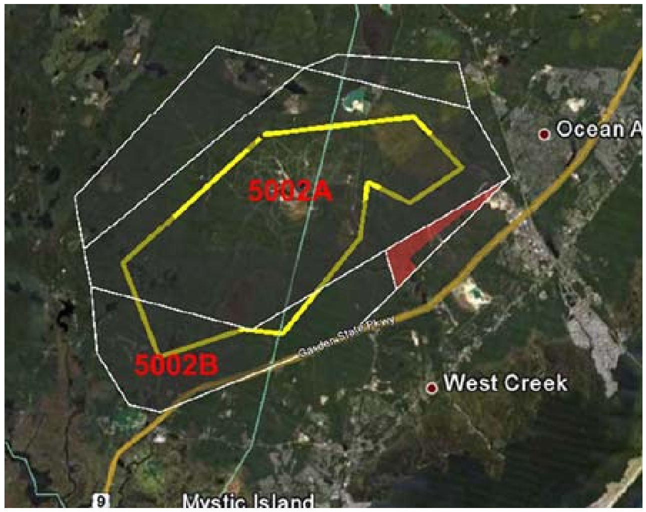

Figure 8. Warren Grove Special Use Airspace

To simulate ATC operations, a notional sector referred to as "Warren Grove Approach" was designed to encompass the operations in and around the Warren Grove SUA. The airspace extended 10NM laterally from the center of the Warren Grove SUA, up to and including 9,000 feet MSL. Surrounding ATC facilities and sector boundaries were adjusted accordingly to adapt to the simulated airspace and staffed by the ghost controller for realism. Figure 9 depicts the simulated Warren Grove Approach airspace.

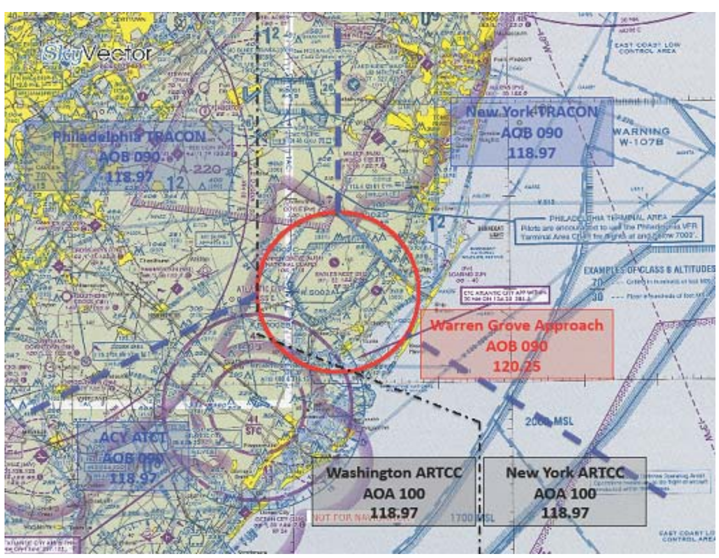

Figure 9. Warren Grove Approach Airspace

2.5.4 Traffic Scenarios

Four unique 35-minute traffic scenarios were developed for this study. For each scenario, the total traffic count for the Warren Grove Approach sector ranged from 14-19 aircraft (including the one UAS) for the 35-minute period. The average number of aircraft being controlled by the Warren Grove Approach sector at any given time was approximately four aircraft.

To create a comparative basis for the study, the set of four traffic scenarios were run one time without NEO services and (the limited) 4D TBO enhancements included. They were then subsequently run a second time, with the addition of NEO services and 4D TBO enhancements, requiring the coupled sFMS to also be included in the runs as well.

In all four scenarios (regardless of NEO services), the Shadow began with the same predetermined flight plan. The first scenario served as a ‘normal case’ operation and did not include any scripted events, equipment failures, or other predetermined reasons for the UAS to deviate from the original flight plan.

The three remaining scenarios (regardless of NEO services) simulated a variety of events: a temporary loss of UAS control and communication (C2) link, a dynamic reroute whereby the UAS crew requested a change to the UAS flight plan, and a strategic conflict where ATC was required to initiate a corrective action (e.g., radar vector, route amendment, change of altitude) to resolve the scripted air traffic conflict.

Note: For the purposes of this study, the lost link event was simulated to be a simultaneous loss of both the uplink and the downlink, while the voice communications link remained intact. During the study in-brief, the UAS Pilots were instructed on lost link procedures for the study. Basically, they were instructed that should a C2 lost link occur, they were to coordinate with ATC and, if possible, continue the mission as planned once/if the links were reestablished.

The scenarios were designed to ensure that traffic levels were high enough to capture a range of complexity and sufficiently busy across sectors (i.e., not too concentrated in one sector over another). All scenarios were tested and verified for accuracy with the support of SME. This validation ensured that the simulated traffic modeled an adequate level of realism and represented a notional, real world air traffic operation.

2.5.4.1 UAS Flight Plan

The Shadow’s base flight plan for the scenarios involved the UAS departing from Warren Grove and transiting into the simulated Warren Grove Approach Control sector, where it flew a pre-determined flight profile circuit at 6000 ft. The flight profile, as depicted (in yellow) in Figure 10, stayed primarily within the Warren Grove SUA 5002 A/B (which was inactive).

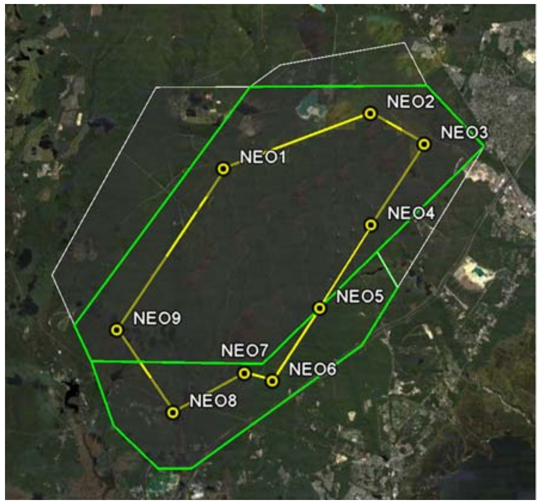

Figure 10. Shadow Planned Flight Plan

As shown in Table 1, there were nine consecutive "NEO" waypoints that comprised the base flight profile circuit for the UAS. The entire circuit, flown at 75 knots indicated airspeed (no wind), took approximately 20 minutes (with no wind).

Table 1. Flight Plan Waypoint Coordinates

NEO Waypoints	(Long)/(Lat)
NEO1	(74°24.55'W)/(39°42.96'N)
NEO2	(74°20.49'W)/(39°44.22'N)
NEO3	(74°16.89'W)/(39°43.50'N)
NEO4	(74°20.49'W)/(39°41.64'N)
NEO5	(74°22.23'W)/(39°39.72'N)
NEO6	(74°23.84'W)/(39°38.04'N)
NEO7	(74°24.77'W)/(39°38.22'N)
NEO8	(74°27.18'W)/(39°37.32'N)
NEO9	(74°29.05'W)/(39°39.24'N)

2.5.4.2 <u>Scenario 1</u>

In Scenario 1, the Shadow flew the predetermined flight plan shown in Figure 10. This scenario did not include any scripted events or deviations.

2.5.4.3 <u>Scenario 2</u>

In Scenario 2, the Shadow began flying the predetermined flight plan shown in Figure 10. During this scenario, at waypoint NEO4, the Shadow experienced a temporary, bi-directional loss of C2 link.

The lost link caused the UAS to engage its pre-programmed lost link procedure. The lost link operational procedure commanded the Shadow to proceed to waypoint LL1 [(74°24.48'W)/(39°42.00'N)], where it initiated a climb to 10,000 feet MSL in an attempt to reacquire the link. By design, at approximately 10,000 feet MSL, the UAS reacquired link. After coordination with ATC, the UAS requested a descent to 6000 feet and resumed the flight plan from waypoint NEO5. Figure 11 depicts the resulting flight plan for this scenario.

During the lost link event planned for this scenario, the Shadow was in conflict with another aircraft as it was in the process of climbing through 8000 ft. to 10,000 ft. This “conflict” aircraft was transiting from en route airspace into the terminal environment.

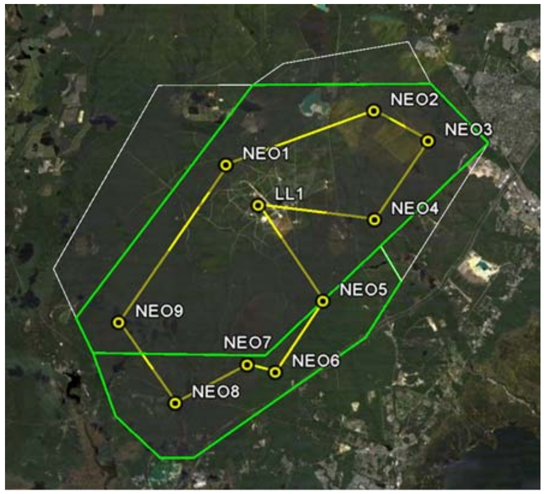

Figure 11. Shadow Lost Link Flight Plan

2.5.4.4 Scenario 3

In Scenario 3, the Shadow began flying the predetermined flight plan shown in Figure 10. By design, at waypoint NEO 3, the Shadow requested a flight plan amendment to accommodate a simulated mission change. From waypoint NEO3, the revised flight plan included waypoints NEO4, NEO1, NEO6, NEO7, NEO9, and NEO1 consecutively.

2.5.4.5 Scenario 4

In Scenario 4, the Shadow began flying the predetermined flight plan shown in Figure 10. By design, at waypoint NEO6, the Shadow came into conflict with a manned aircraft, requiring the controller to issue a control instruction. The intent of this planned event was for the controller participant to use his skills, experience, and available tools to resolve the conflict.

2.5.5 Informed Consent

Each participant read and signed an informed consent form prior to the commencement of the study. Informed consent forms ensure voluntary participation in the study, assure participant anonymity, and outline any risks the participants may be subjecting themselves to by participating.

2.5.6 Biographical Questionnaire

Each participant completed a biographical questionnaire before the experiment. The participants provided general biographical information about themselves, including gender, age, and level of relevant experience.

2.5.7 Post-Run Questionnaires

After completing each simulation run, the participants provided subjective ratings about their experience during the run, including their own performance, workload, and situation awareness, by making ratings on a Post-Run Questionnaire (PRQ). Separate PRQ assessed the Air Traffic Controller, UAS Pilot, and FMS Operator participants. The participants also had the opportunity to provide open-ended responses, which included any information about the scenario they considered relevant.

2.5.8 Post-Experiment Questionnaire

The participants completed a Post-Experiment Questionnaire (PEQ) after completing the entire study. On the PEQ, the Air Traffic Controller, UAS Pilot, and FMS Operator participants had the opportunity to provide their opinions regarding general characteristics of the experiment (e.g., realism).

2.5.9 Observer Rating Forms

The SME Observers used a brief Observer Rating Form (ORF) to provide an independent assessment of the operation and to capture their insights into any unusual occurrences observed during the study runs. These forms did not evaluate the performance of the participants but merely described information not captured by other data sources.

2.5.10 Training

The first day of the simulation was dedicated to training. Training scenarios were run until all participants reported they were familiar with the airspace and operations involved.

2.6 Experimental Design

Operational descriptions of the scenarios designed for the study are detailed in Section 2.5.4. Table 2 summarizes the scenario conditions simulated during the study. Due to schedule complications, the researchers had limited ability to randomize the presentation order of the scenarios. Scenarios were presented in the following order: Run 2B, Run 3B, Run 4B, Run 1B, Run 4A, Run 3A, Run 2A, Run 1A.

Table 2. Scenario Conditions

SCENARIO	Run Name	With NEO Services and sFMS	EVENT
1	1A	No	No Event
2	2A	No	Temporary Bi-directional Lost Link @ NEO4
3	3A	No	Flight Plan Amendment @ NEO3
4	4A	No	Conflict A/C @ NEO6
1	1B	Yes	No Event.
2	2B	Yes	Temporary Bi-directional Lost Link @ NEO4
3	3B	Yes	Flight Plan Amendment @ NEO3
4	4B	Yes	Conflict A/C @ NEO6

2.6.1 Independent Variables

The primary independent variable was the NEO services and sFMS/GCS coupling. This variable has two levels: 1) NEO services and sFMS present, and 2) NEO services and sFMS absent. In addition, a second independent variable was the type of event presented in the scenario. This variable had four levels: 1) no event, 2) temporary lost link, 3) UAS initiated flight plan amendment, and 4) UAS in conflict with a manned aircraft.

2.6.2 Dependent Variables

Subjective and objective data were collected throughout the study from both the air traffic perspective (via the Air Traffic Controller, Ghost Controller, SME observer, and ATC simulation automatic data capture components) and the UAS perspective (via the UAS Pilot, FMS Operator, SME Observer, and GCS auto data capture components). Specific variables measured are described in the following sections.

2.6.2.1 Objective Data

For each run, ATC operational system performance, safety, and voice communications data were collected from both the TGF and DESIREE systems. For this limited HITL study, the following ATC operational metrics were collected during each of the scenario runs:

- Total number of aircraft handled during the scenario
- Average number of controlled aircraft per sector at any given time
- Operational errors
- Collisions
- Loss of separation (LOS)
- Duration of each LOS in seconds
- Number of conflicts (planned vs. actual)
- "Event" characterization

Several UAS operational performance measures were also recorded. The metrics and the sources for their measures appear in Table 3.

Table 3. UAS Objective Data Summary

UAS Performance Metrics		
Data Type	**Data Capture**	**Data Source**
Minimum Separation Distance for any conflicts involving UAS simulator	During each run	TGF, UAS simulator output data
Number of separation violations for any conflicts involving UAS simulator	During each run	TGF, UAS simulator output data
Type of maneuvers made by UAS simulator	During each run	UAS simulator output data and audio/video (A/V) recordings
System performance/response latencies	During each run	UAS simulator output data and A/V recordings (Record both UAS performance accuracy/latency and Pilot response accuracy/latency)
Pilot latency to respond to ATC control instructions, and duration of response	During each run	Close-up video recording of UAS Pilot inputs, DESIREE “easy button” timestamp

2.6.2.2 Subjective Data

A variety of subjective data was collected from the study participants and the SME observers throughout the study. The data included ratings and opinions regarding the operations, tools, information provided, workload, situation awareness, and scenario events, etc. As described in the Materials Section (Section 2.5), subjective data was collected from the study participants via written Biographical Questionnaires, PRQ, and PEQ. The SME Observers provided written information via the ORF during each run. Both the participants and SME Observers also provided verbal input concerning their experiences during guided, but unstructured, debriefs at the end of each day. The debrief discussions were audio recorded.

In addition, instantaneous workload ratings were made by the Air Traffic Controller and UAS Pilot every four minutes during each run using the WAK. If a participant failed to respond within the 20-second time limit, then the associated data point for the individual workload rating was considered as missing data.

2.7 Procedure

2.7.1 General Schedule of Events

One Air Traffic Controller, one UAS Pilot, and one FMS Operator were utilized to complete the study (a total of three participants). These participants were scheduled for two days of testing. The first day of the HITL study included instructional in-briefs, training, three data collection runs, and a debrief sessions. The second day included refresher training, four data collection runs, and a final debrief designed to obtain participant feedback on the overall study. Figure 12 illustrates the daily schedule of events, including the simulation runs.

	Tuesday	**Wednesday**
8:30	Welcome, Inbrief & Training	Training, Review
8:45		
9:00		Run 1b
9:15		
9:30		Break/Questionnaires
9:45		
10:00		Run 4a
10:15		
10:30	Training Scenarios	Break/Questionnaires
10:45		
11:00		Run 3a
11:15		
11:30	Lunch	Break/Questionnaires
11:45		
12:00		Lunch
12:15	Run 2b	
12:30		
12:45	Break/Questionnaires	Run 2a
1:00		
1:15	Run 3b	Break/Questionnaires
1:30		
1:45	Break/Questionnaires	Run 1a
2:00		
2:15	Run 4b	Break/Questionnaires
2:30		
2:45	Break/Questionnaires	Formal Debrief and Discussion
3:00		
3:15	Debrief and Discussion	
3:30		
3:45		
4:00		
4:15		

Figure 12. Schedule of Runs

2.7.2 In-Briefing

On the first day of the study, introductions were made and all participants were briefed on the background and objectives of the study prior to participating. After the briefing, the participants completed a consent form, which assured their anonymity and voluntary participation in the study, along with a background questionnaire, which collected information relating to their ATC or UAS experience. An SME then gave a brief overview of the airspace, procedures, and simulated laboratory environment the participants were to experience. All participants were briefed together due to the limited scope of the study.

2.7.3 Practice Scenarios

Following the in-brief, the participants were escorted to their respective laboratories and given an overview of the laboratory equipment. They then completed training runs to familiarize themselves with the laboratory and data collection procedure. Training was overseen by test personnel.

2.7.4 Data Collection Procedure

During data collection, the participants worked a total of eight 35-minute simulation runs. The participants adhered to all applicable existing Department of Defense and FAA procedures, standard operating practices, and the Letter of Agreement for the airspace environment. While participants worked each scenario, they provided workload ratings on the WAK every four minutes. SME observers also observed each domain and collected the dependent measures required in the ORF.

Following each run, the participants completed the PRQ appropriate for their position. Participants then were given an approximately 30-minute break before the next scenario began. This procedure was repeated until all eight test scenarios were complete.

After the data collection runs were complete, participants filled out a PEQ and met to participate in a final debrief. During the debrief session, the participants provided feedback on the study and the researchers answered any questions the participants had concerning the study and the concepts being investigated. The debriefing was audio recorded for data analysis purposes.

3. Data Analysis

This research endeavor was purposely designed to be a limited-scope HITL simulation focused on exploring and demonstrating proposed concepts for network-enabled information sharing and UAS operations in the NAS. It is duly acknowledged that the data sample was very small and the number of participants equally limited. By design and known limitations, it was projected that statistical analyses resulting from this limited study would be exclusively descriptive in nature. As expected, this simulation does not provide data with statistical rigor (i.e., there was insufficient power for the use of inferential statistics), nor can it validate the proposed operations or concepts under investigation. This exercise does, however, provide an opportunity for early visualization of the proposed concepts as well as a glimpse of information concerning the impact of the proposed operations in the NAS environment.

As a study with accepted limitations, all data and results are interpreted and presented with due caution. Results cannot be generalized or accepted as conclusive.

4. Results

4.1 Participants

One UAS Pilot participant was required for this study. This participant was a 32-year-old male. At the time of the study, he had 14.5 years of experience as a UAS Crewmember and had accumulated 700 hours as a UAS Pilot, 400 hours as a Sensor Operator (SO), and 100 hours as a Mission Commander (MC). This individual is neither a certificated manned aircraft pilot nor a rated military pilot. The participant's most recent qualification training was over 6 years ago, but he has actively piloted and performed the SO role in all of the previous 12 months. On a seven-point scale, this individual rated his UAS Pilot skills as a 7, "very skilled," and his level of motivation to participate in this study also a 7, "very motivated." He reported that, on the UAS crew with which he most typically works, the Pilot, SO, and MC positions are all usually staffed. He reported that of these positions, the MC is the individual who typically communicates directly with ATC. The participant has actively served in the MC position for two of the previous 12 months. When asked to rate his experience communicating with ATC in the NAS, he rated it a 2 on the seven-point scale, with 1 corresponding with "No Experience" and 7 corresponding with "Very Experienced."

The participant who served in the FMS Operator position was a male and 66 years of age. This individual was a certificated manned aircraft pilot, but was not a rated military pilot. At the time of the study, he reported having five months of experience working as part of a UAS crew, exclusively in the position as an FMS Operator. He most recently completed currency FMS training two years ago, and has accumulated a total of 12,000 hours working with FMS systems (spanning his 25 years' experience as an air carrier pilot). He reported having actively operated an FMS as a UAS crewmember in one of the previous 12 months. On a seven-point scale, this individual rated his skill as an FMS Operator a 7, "very skilled," and his level of motivation to participate in this study a 6, with 7 corresponding to "Very Motivated."

One Air Traffic Controller participant was required for this study. This participant was a 50-year-old male who retired from the FAA on August 31, 2010 after 27.5 years as a Certified Professional Controller. Of those 27.5 years, 21 years were spent actively controlling traffic in a Terminal Radar Approach Control facility, with the remaining 6.5 years spent actively controlling traffic in an Air Route Traffic Control Center (ARTCC). On a seven-point scale, this individual rated his skill as an Air Traffic Controller a 7, "very skilled," and his level of motivation to participate in this study a 6, with 7 corresponding to "very motivated." This participant reported that he had no prior ATC experience with UAS operations at any of the facilities where he previously controlled traffic.

4.2 Scenario Specific Subjective Data

The results from the subjective data sources for each scenario are described below. This includes summaries of any important results found in the PRQ and ORF.

4.2.1 Scenario 1

In Scenario 1, the "normal case" scenario with no scripted events, there were minimal differences observed between Scenario 1A (without sFMS and NEO services) and Scenario 1B (with sFMS and NEO services).

In this scenario, when asked to rate the degree to which NEO affected the predictability of the UAS as well as the communications with the UAS crew, the Air Traffic Controller participant rated both a "4" on a seven-point scale (with "1" corresponding to "not at all" and "7" corresponding to "a great deal"). This participant did comment, though, that the Airspace Volume of Interest (AVOI) service provided UAS flight plan route data that is not typically available in the STARS system.

The FMS Operator rated the degree to which the availability of NEO services contributed to his workload a “2” on a seven-point scale (with “1” corresponding to “not at all” and “7” corresponding to “a great deal”). In this scenario, the participant commented that since there was not any complicated route data needed to be communicated to ATC, NEO services appeared to be relatively transparent. However, when asked to rate the degree to which the availability of NEO services affected his ability to coordinate effectively with ATC, he rated this “6” on the same seven-point scale. He also supplemented this response with the comment that “NEO helps us as a crew to communicate our trajectory to ATC in a precise manner.”

According to the UAS Pilot’s responses, it appears as though the only area in this scenario on which the addition of the sFMS and NEO services had a direct impact was his workload. The UAS Pilot rated the degree to which the availability of the sFMS contributed to his workload as “5”, and the degree to which NEO services contributed to his workload a “1,” on seven-point scale (with “1” corresponding to “not at all” and “7” corresponding to “a great deal”). He also commented that NEO services reduced his workload. As such, it is possible that the increase in workload due to the availability of the sFMS may be attributed to the additional level of coordination required with the added crewmember and new technology introduced.

4.2.2 Scenario 2

The data from Scenario 2, which included the temporary lost link event, revealed some observed differences between the run with the sFMS and NEO services (Scenario 2B) and the run without (Scenario 2A).

Most of these differences were observed from the air traffic perspective. For example, the Air Traffic Controller rated that the degree to which handling the UAS contributed to his workload a “5” during Scenario 2A and a “2” during Scenario 2B. These ratings were made on a seven-point scale, with “1” corresponding to “not at all” and “7” corresponding to “a great deal.” On the same scale, the Air Traffic Controller rated the degree to which communication and coordination with the adjacent sector affected his workload a “3” for Scenario 2A and a “1” for Scenario 2B. These observations both show a decrease in Air Traffic Controller workload when the sFMS and NEO services were available.

In addition to the decreased ratings in workload, there is also data to suggest an increase in the Air Traffic Controller’s confidence in UAS operations with the sFMS and NEO services. This is supported by the responses to multiple Likert scale items. The Air Traffic Controller rated the degree to which UAS required additional attention a “6” in Scenario 2A and a “3” in Scenario 2B. The degree to which priority handling was provided to the UAS was rated a “6” in Scenario 2A and a “1” in Scenario 2B. Furthermore, the Air Traffic Controller rated his confidence level for safe operations a “5” in Scenario 2A and a “7” in Scenario 2B. This data may be able to be explained by an increase of confidence, on the part of the Air Traffic Controller, due to the flight plan data displayed by NEO services, specifically during the lost link event. To further support this notion is the fact that, in the run without sFMS and NEO services, the Air Traffic Controller provided an extra margin of spacing for the UAS to protect for unplanned route excursions. However, he did not provide this same margin of spacing in the run without sFMS and NEO services.

The SME Observer for the Air Traffic Controller also commented that the sFMS and NEO services appeared to aid the Air Traffic Controller during the lost link event since it allowed him to visualize the lost link flight plan. He further explained that these services improved the precision of coordination during lost link because the pilot did not have to "issue lat/longs for lost link point." The Air Traffic Controller knew that point was in SUA but not where in the area."

From the perspective of UAS operations, there were also several notable differences between the operations with and without NEO services and the sFMS, but the trend of observations was not as clear cut. For example, differences can be seen between Scenarios 2A and 2B with regard to the UAS Pilot's workload and ability to coordinate with ATC. Specifically, in Scenario 2A, the UAS Pilot rated his effort a "2" on a seven-point scale (with "1" corresponding to "extremely low" and "7" corresponding to "extremely high"), versus a "5" for Scenario 2B with NEO services and the sFMS. This may be explained by the increased coordination required with the additional crewmember. Conversely, the Pilot reported that his overall workload decreased when adding the sFMS and NEO services, rating overall workload a "4" in Scenario 2A and a "2" in Scenario 2B, on the same seven-point scale as effort. Additionally, his rating on the degree to which communication with ATC contributed to his workload also showed a decrease from a "6" to a "3" (on a seven point scale with "1" corresponding to "not at all" and "7" corresponding to "a great deal") when sFMS and NEO services were added. However, despite his decreased rating, the Pilot commented that he did not feel NEO affected his workload at all since he did not directly deal with the NEO services, but rather coordinated with the FMS Operator throughout the duration of the flight.

In terms of the ability to coordinate with ATC, it appears within this scenario as though the addition of the sFMS and NEO services had a positive impact. When asked to rate the degree to which the sFMS affected his ability to coordinate with ATC, the UAS Pilot rated it a 5 out of 7 (with "1" corresponding to "not at all" and "7" corresponding to "a great deal"). He stated that this rating was due to the benefit that the sFMS sent UAS intent and location of the lost link point directly to ATC. On the other hand, the degree to which the availability of NEO services affected the ability to coordinate with ATC was rated a "1" on the same scale, alluding again to the notion that the Pilot may have felt that NEO services were rather transparent to the UAS Pilot's role since he was not the one directly interfacing with the NEO system.

It must also be reported that the initial data review identified a separation violation between two aircraft during Scenario 2B. However, upon further analysis, it was definitively determined that the LOS event was the direct result of a simulation process error and therefore is not being considered a valid LOS during the simulated operation. For this reason, no further data is reported.

4.2.3 Scenario 3

In Scenario 3, in which the UAS Pilot requested a flight plan reroute, most of the differences in data between the run with the sFMS and NEO services (Scenario 3B) and the run without (Scenario 3A) were seen from the UAS perspective.

The majority of these differences were in regard to the UAS Pilot's workload. The following measures were all recorded on a seven-point scale, with "1" corresponding to "extremely low" and "7" corresponding to "extremely high." The UAS Pilot reported his mental and temporal demands as "5" and “4,” respectively, for Scenario 3A. He then rated both measures a “2” for Scenario 3B. He also reported that his overall workload decreased from “5” to “2” from Scenario 3A to Scenario 3B. In addition to reporting a decrease in workload and demand ratings, the Pilot also seemed to feel that his performance improved with less effort required when the added services were available. He rated his performance and effort a “5” and “6,” respectively, for Scenario 3A and a “7” and “3,” respectively, for Scenario 3B.

Another way in which the sFMS and NEO services appeared to assist the UAS Pilot was related to the workload associated with coordination with ATC. When asked to rate the degree to which communication with ATC contributed to the UAS Pilot’s workload, he responded with a “6” rating in Scenario 3A and a “2” rating in Scenario 3B, on a seven-point scale (with “1” corresponding to “not at all” and “7” corresponding to “a great deal”). He also commented that NEO “eased workload by auto-sending points to ATC” for the requested flight plan reroute. For this same reason, the UAS Pilot also rated the degree to which the sFMS affected his ability to coordinate effectively with ATC a “5” on the same seven-point scale.

The FMS Operator made similar observations on the effect of the availability of NEO services on the workload of the UAS crew. He rated the degree to which the availability of NEO services affected his ability to coordinate effectively with ATC a “5” on the same seven-point scale discussed in the previous paragraph. The FMS Operator also commented that “NEO helps considerably with a pilot-requested reroute by eliminating the need to read lat/longs” and that since “we as a crew did not have to read complex data to ATC, we could devote full attention to safe airplane operations.”

There appeared to be minimal differences from the air traffic perspective between Scenarios 3A and 3B. However, the differences that were present seemed to further support the UAS Pilot and FMS Operator’s comments regarding the apparent increased ease of coordination with the addition of the sFMS and NEO services. When asked to rate the degree to which the availability of NEO services affected the predictability of the UAS and the efficiency of communication and coordination with the UAS crew, the Air Traffic Controller rated both a “5” on a seven-point scale, with “1” corresponding to “not at all” and “7” corresponding to “a great deal.” He also commented that the “AVOI provided flight plan route data that is not normally available in STARS.” The SME Observer noted that during Scenario 3A, when sFMS and NEO services were not present, the “Shadow’s route change issuing lat/longs requires controller’s eyes off scope,” suggesting a potential negative consequence from the cumbersome coordination of the lat/long system.

A separation violation was also initially identified in Scenario 3B. After carefully examining the data, it was definitively concluded that a laboratory distraction temporarily affected the Air Traffic Controller’s ability to conduct his role in the study, therefore resulting in a LOS between two aircraft in the run. Since the cause was non-native to a realistic operational environment, this event is not considered a valid LOS for the operation and no further data is reported.

4.2.4 Scenario 4

Scenario 4, in which the UAS was in conflict with a manned aircraft at NEO waypoint 6, showed a similar trend of results as Scenario 3. That is, most of the apparent differences between the run with the sFMS and NEO services (Scenario 4B), and the run without these services (Scenario 4A), were from the UAS perspective.

Again, most of the metrics that appeared to be affected were related to the UAS Pilot's workload and coordination with ATC. The measures discussed in this paragraph were all rated on a seven-point scale with "1" corresponding to "extremely low" and "7" corresponding to "extremely high." The UAS Pilot rated his effort a "4" and a "2" in Scenarios 4A and 4B, respectively. In addition, when asked to rate overall workload and complexity, the Pilot rated these both a "4" for Scenario 4A and a "2" and "1", respectively, for Scenario 4B. These data suggest an overall decrease in the UAS Pilot's workload with the addition of the sFMS and NEO services. Comments made by the SME Observer concerning the UAS Pilot also suggest decreased workload with the added services. The SME Observer was asked his perception of the overall workload and complexity of the two scenarios and rated both metrics a "4" for Scenario 4A and a "2" for Scenario 4B, on the same scale mentioned above. The SME Observer commented that in Scenario 4A, the UAS Pilot "appeared to spend less time on the camera due to the workload of manually flying the UAS."

Another possible indicator of reduced workload is the Air Traffic Controller rating the degree to which handling UAS contributed to his workload a "3" in Scenario 4A and a "1" in Scenario 4B. These ratings were made on a seven-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal."

Another workload-related metric that showed apparent differences between the two scenarios was the degree to which communications with ATC contributed to the workload of the UAS Pilot. The UAS Pilot rated this a "5" for Scenario 4A and a "2" for Scenario 4B, again on a seven-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal." The UAS Pilot also stated that in Scenario 4A the UAS was given a "direct to" instruction from ATC and, although the Pilot followed ATC's instruction, he "needed a repeat of coordinates due to the amount of information given." This comment seems to support other observations that suggest the current UAS lat/long coordinate-based navigation system may be an issue for operations in the NAS environment.

Similar to the findings of previous scenarios, when asked to rate the degree to which the sFMS affected his ability to coordinate with ATC, the UAS Pilot rated it a 5 out of 7 (with "1" corresponding to "not at all" and "7" corresponding to "a great deal"). Again, the degree to which the availability of NEO services affected the ability to coordinate with ATC was rated a "1" on the same scale, further supporting the idea of the apparent transparency of NEO services to the UAS Pilot.

4.3 Overall Workload Ratings

The graphs in Figure 13 and Figure 14 display the average Air Traffic Workload Input Technique (ATWIT) ratings for each run. The ATWIT ratings are the measures collected via the WAK keypad at the Air Traffic Controller and UAS Pilot positions.

Both graphs appear to show a slight decrease in workload from the "A" Scenarios (without sFMS and NEO services) to the "B" Scenarios (with sFMS and NEO services). It should be noted, however, that average workload appeared to be relatively low across all runs, for both positions, as the averages all fell below "4" on the seven-point WAK scale described in Section 2.4.7.

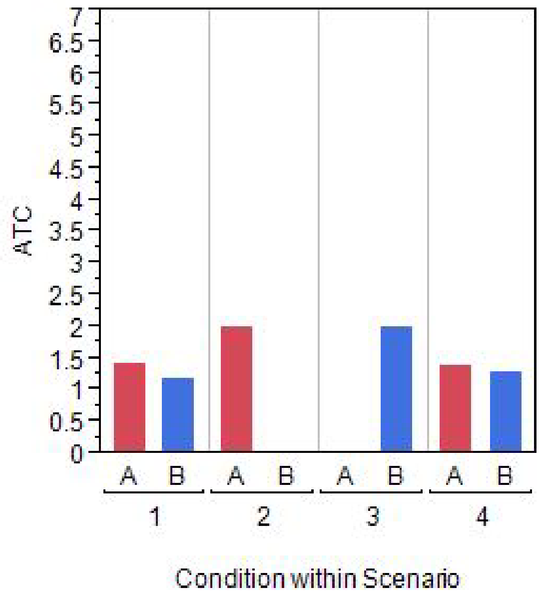

Figure 13. Average ATWIT Ratings for the Air Traffic Controller Participant

Note: Due to missing data entries, as a result of certain simulation conditions, the averages for Scenarios 2B and 3A were not reported.

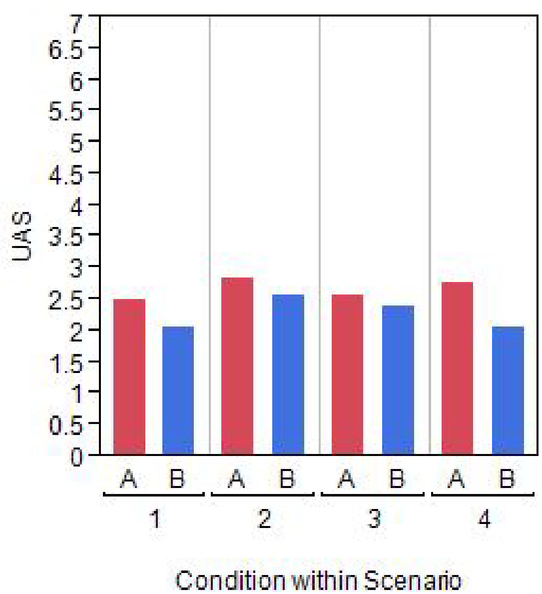

Figure 14. Average ATWIT Ratings for the UAS Pilot Participant

4.4 Post Experiment Questionnaires

Overall, participants reported that the addition of the sFMS and NEO services seemed to improve their ability to perform their duties efficiently and effectively.

Specifically, the FMS Operator in this study reported that the availability of NEO services improved his overall ability to conduct his missions because it made it easier to communicate complex information to ATC. This participant also offered possible suggestions as the team moves forward with the development of these concepts. The FMS Operator commented that the ability to display the entire CAP message on the sFMS workstation before it was loaded would allow the FMS Operator and UAS Pilot to pre-coordinate clearances with ATC prior to execution. In addition, this participant suggested that the ability to generate AVOI data from manual sFMS entries would provide for safer UAS NAS integration.

The UAS Pilot reported that the availability of the integrated sFMS improved his overall ability to conduct the missions, as it allowed for greater ease in communicating flight plan changes to ATC. However, when asked specifically about NEO services, the UAS Pilot did not perceive a notable improvement. This may be attributed to the fact that the UAS Pilot was not the individual who was directly engaged with the system since, by simulation design, it was the responsibility of the FMS Operator to directly communicate the CAP messages and NEO information to ATC.

The Air Traffic Controller noted that the availability of NEO services improved his coordination and collaboration with the overlying ARTCC, as it allowed for a more accurate visualization of the UAS route of flight. In addition, the Air Traffic Controller also reported that the addition of the sFMS and NEO services appeared to improve the predictability of UAS operations since it provided the ability to display the route and coordinate directly with the UAS crew. Although the NEO services seemed to assist the Air Traffic Controller in his ATC duties, he suggested refining the NEO prototype interface, which reportedly became distracting at times due in part to the fact that the alerts are constant and non-selectable.

This Air Traffic Controller also offered observations with regard to UAS NAS integration issues in general. He reported that UAS operations specifically affect the Air Traffic Controller's workload during a lost link event in which a reroute of the flight plan is required using lat/longs. For this reason, he identified the need to somehow standardize UAS lost link procedures before allowing for more routine UAS NAS integration.

4.5 Debriefing Summary

During the debrief discussion at the conclusion of all simulation runs, the participants made numerous comments regarding the benefits of the availability of both the sFMS and NEO services on UAS operations in the NAS.

Specifically, the Air Traffic Controller stated that he felt the ability to display the real-time 4D trajectory of the UAS was especially helpful when dealing with route amendments that involved the use of a different coordinate system. He cited flight plan amendments of military operations using lat/long coordinates as a prime example of a typically cumbersome situation that, in his opinion, would be made smoother by the availability of NEO services. Concerning flight plan amendments, the UAS Pilot also commented that he noticed that ATC seemed to be receiving the information and responding quicker in the run involving the sFMS and NEO services than in the run without those services.

Another situation in which the Air Traffic Controller identified NEO services as being beneficial was during the lost link event. He stated that, in this situation, NEO services eliminated the usual "20 questions" associated with acquiring the UAS' location and intent information. This was accomplished through the ability of NEO services to display the lost link mission instantaneously and accurately. According to the Air Traffic Controller, this capability proved to be very valuable and aided in the Air Traffic Controller's ability to handle this situation. The UAS Pilot echoed this notion and stated that he felt the ability to send the lost link route automatically through the intent messaging was very beneficial.

When the UAS Pilot and FMS Operator were asked specifically about their collaboration, both stated they felt the configuration worked well for the sake of the study. They both felt communication flowed smoothly between them and it was helpful for both of them to be able to monitor the aircraft and assist with the scripted events. However, the FMS Operator also felt that, moving forward, the sFMS should be integrated directly into the UAS GCS and operated by the UAS Pilot to allow for ease of use and eliminate the third party coordination.

Recognizing that the systems included in the study are conceptual and only prototypes, the participants offered suggestions for moving forward with the development of the NEO services. The Air Traffic Controller suggested (as on the PEQ) that the NEO prototype interface be reconfigured. He felt that once the whole route of the aircraft was displayed, it would be beneficial to have the ability to then hide that information to make the display slightly less cluttered. This participant also commented that the alerts were distracting and "too much," as some similar features are already available in STARS. An additional point of consideration discussed was the arenas in which the 4D TBO technologies will be deployed once fully developed. The Air Traffic Controller commented that, although there seemed to be benefits to making these technologies available in the terminal environment, as was demonstrated in this study, it would most likely be of little to no value to implement these technologies in the en route environment, as similar tools already exist in the automation system.

4.6 Further Data Analysis

In addition to the results presented in this report, further data analysis is planned involving the UAS system data, the ATC system data, and the voice communications data from this study. For example, data from this simulation can be used to analyze additional UAS and operator response times. These additional results would contribute to the FAA's goal of gathering baseline UAS performance data in the NAS environment, further supporting the UAS safety case.

5. Conclusion

In conclusion, this limited-scope HITL simulation, which demonstrated the proposed NEO services and 4D TBO concepts, suggests that pairing these concepts with an FMS-equipped UAS provides for improved coordination between ATC and the UAS crew in the normal case and event driven scenarios as simulated.

Study observations also appear to show that ATC experienced improved predictability of UAS operations during lost link events, as well as increased ease of coordination of flight plan amendments and reroutes with the UAS crew when these concepts were implemented.

With further refinement of the procedures and technologies presented, the general concepts simulated appear to merit further exploration. To robustly evaluate the potential impact of the concepts introduced, it is recommended that comprehensive validation studies be conducted.

References

Federal Aviation Administration (2010). UAS Integration Evaluation Plan. Atlantic City, NJ.

Harry G. Armstrong Aerospace Medical Research Laboratory Publication. Wright-Patterson Air Force Base, OH.

NEO Spiral II Final Report Executive Summary" document D794-10221-1, January 25, 2012

Acronyms

4D TBO	4 Dimensional Trajectory Based Operations
6 DOF	6 Degrees of Freedom
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATM	Air Traffic Management
ATWIT	Air Traffic Workload Input Technique
Audio/Video	A/V
AVOI	Airspace Volume of Interest
C2	Control and Communication
CAP	Common Alerting Protocol
CRDA	Cooperative Research and Development Agreement
DEX	Data Exchange
DESIREE	Distributed Environment for Simulation, Rapid Engineering, and Experimentation
FAA	Federal Aviation Administration
FCS	Flight Control System
FMS	Flight Management System
GCS	Ground Control Station
HILSIM	Hardware-in-the-Loop Simulator
HITL	Human-in-the-Loop
LOS	Loss of Separation
MC	Mission Commander
MPLS	Multi-Protocol Label Switching
MSL	Mean Sea Level
NAS	National Airspace System
NEO	Network Enabled Operations
NextGen	Next Generation Air Transportation System
NIEC	NextGen Integration and Evaluation Capability
ORF	Observer Rating Form
PEQ	Post-Experiment Questionnaire
PRQ	Post-Run Questionnaire
R&D	Research and Development
SO	Sensor Operator
sFMS	Simulated Flight Management System
SME	Subject Matter Expert
STARS	Standard Terminal Automation Replacement System
SUA	Special Use Airspace
SWIM	System Wide Information Management
TGF	Target Generation Facility
UAS	Unmanned Aircraft System
WAK	Workload Assessment Keypad
WJHTC	William J. Hughes Technical Center

Appendices

Appendix A - R5002 Restricted Area Details

Appendix A – R5002 Restricted Area Details

The description of the following restricted areas is from FAA Order 7400.8T and is only provided as general information. The legal descriptions are published in the Federal Register.

<u>R-5002A Warren Grove, NJ</u>

Boundaries. Beginning at lat. 39°43'25"N., long. 74°17'36"W.; to lat. 39°38'25"N., long. 74°24'19"W.; to lat. 39°38'30"N., long. 74°29'29"W.; to lat. 39°39'20"N., long. 74°29'59"W.; to lat. 39°44'50"N., long. 74°24'39"W.; to lat. 39°44'50"N., long. 74°19'19"W.; to the point of beginning.
Designated altitudes. Surface to 14,000 feet MSL.
Time of designation. Sunrise to sunset, other times as activated by NOTAM issued at least 48 hours in advance.
Controlling agency. FAA, New York ARTCC.
Using agency. Air National Guard, 108th Air Refueling Wing, McGuire AFB, NJ

<u>R-5002B Warren Grove, NJ</u>

Boundaries. Beginning at lat. 39°41'00"N., long. 74°20'51"W.; to lat. 39°40'10"N., long. 74°20'14"W.; to lat. 39°38'50"N., long. 74°21'19"W.; to lat. 39°36'00"N., long. 74°26'29"W.; to lat. 39°36'00"N., long. 74°27'29"W.; to lat. 39°37'00"N., long. 74°28'49"W.; to lat. 39°38'30"N., long. 74°29'29"W.; to lat. 39°38'25"N., long. 74°24'19"W.; to the point of beginning.
Designated altitudes. 1,000 feet MSL to 14,000 feet MSL.
Time of designation. Sunrise to sunset, other times as activated by NOTAM issued at least 48 hours in advance.
Controlling agency. FAA, New York ARTCC.
Using agency. Air National Guard, 108th Air Refueling Wing, McGuire AFB, NJ.